

plane transport tunnel can be reserved between the MeNB and the SeNB so that an Xn signaling message can be used to indicate the data unit index as well. This can support the TDM-based dual connectivity while minimizing UE impacts. The UP data unit index could be a protocol data unit (PDU) index like a Packet Data Convergence Protocol (PDCP) Sequence Number (SN), a Radio Link Control (RLC) Sequence Number (SN), or a number of bytes, depending on how UP data mirroring is adopted.

[0092] Next, embodiments of the present invention can also switch a UE from the SeNB back to the MeNB. Prior to switching from the SeNB back to the MeNB, if the data that was mirrored to the SeNB has already been fully transmitted by the SeNB to the UE (i.e., the SeNB has transmitted all of its data and has run out of data to transmit to the UE), the SeNB should indicate to the MeNB that, in the future, more user data should be mirrored from the MeNB to the SeNB. By mirroring more data from the MeNB to the SeNB, the SeNB radio resource can be used more effectively. Conversely, if the SeNB has not fully transmitted the mirrored data to the UE by the time the UE is supposed to switch from the SeNB back to the MeNB, and the remained rate is higher than a threshold, then the amount of redundancy should be reduced. The remained rate can be considered to be the ratio of non-transmitted data over mirrored data. If this rate is high, it can mean that the redundancy is also high and should be reduced.

[0093] During switching from the SeNB to the MeNB, the MeNB should be aware of the latest UP data index which has been successfully transmitted. In certain embodiments, the UE informs the MeNB of the latest UP data unit index which has been transmitted successfully via a Radio Resource Control (RRC) message (via either Packet Data Convergence Protocol (PDCP) or via a Radio-Link-Control (RLC) Protocol-Data-Unit (PDU)). The MeNB can thus start transmitting from the next packet. To achieve the above informing, a new IE can be added to the RRC message, or a new RRC message can be dedicated for such a purpose. In one embodiment, a higher priority control plane transport tunnel can be reserved between the MeNB and the SeNB so that an Xn signaling message can be used to indicate the data unit index as well. This can support the TDM-based dual connectivity while minimizing UE impacts.

[0094] After the UE switches back to the MeNB, the MeNB can remove all the user data which has been mirrored to the SeNB and that has been successfully transmitted to the UE. The MeNB can then start to calculate the amount of user data to be mirrored in a next cycle.

[0095] Embodiments of the present invention can be used in conjunction with high bandwidth downlink traffic. The DL data arrival rate can be high so that the MeNB can have certain accumulated buffered data before the UE switches from the MeNB to the SeNB. This can happen in cellular networks with cloud RANs supporting content-distribution. As such, the eNB may be connected with a large content server, or the MeNB can work in a high-load status due to a large number of UEs that are camped on a macro cell. For such traffic, the MeNB can buffer some traffic without using too much macro eNB resources and can allow more traffic to be served by the SeNB. Meanwhile, latency and latency jitter can be minimized, and the SeNB radio resources can be fully utilized.

[0096] FIG. 2 illustrates an example procedure in accordance with one embodiment of the present invention. As shown in FIG. 2, in order to indicate a last data unit transmitted or next data unit to transmit by the MeNB or the SeNB,

one embodiment can use new and/or extended RRC messages. The UE can transmit an indication of either the last data unit that has been transmitted already, or an indication of the next data unit to transmit. Another embodiment can reserve a high priority control plane transmission tunnel between the MeNB and the SeNB, and can also use Xn AP messages to indicate the last data unit. As described above, such embodiments can reduce impacts to the UE during switching. The UE can save the control signaling and can also reduce standardization efforts to support such TDM-based dual connectivity for a single RX/TX UE.

[0097] The timing of a buffering operation can be determined by the TDM pattern selected and/or the minimum time granularity, e.g., sub-frames.

[0098] The amount of UP data to be mirrored to the SeNB could have some redundancy to allow for maximum usage of SeNB radio resources. This means, more UP data (than the amount which can be transmitted by the SeNB in a cycle) can be mirrored to the SeNB before switching. Upon switching back to the MeNB, it is possible that not all the mirrored UP data has been transmitted. Then, after the UE has switched to the MeNB, the SeNB can remove the data which has been transmitted to the UE. UP data mirroring in the SeNB can be continued and the SeNB can remove all the UP data units which have been transmitted to the UE via the macro eNB.

[0099] For UP data mirroring operations, PDCP or RLC PDU can be packetized in the MeNB and then mirrored to the SeNB. If PDCP or RLC packetization is performed in the SeNB, the MeNB can just mirror the bytes of the UP data and be informed of the byte index.

[0100] From an entity/device point of view, the operations can be summarized as follows. From the perspective of the MeNB, during preparation of switching between the MeNB and the SeNB, the MeNB can get the SeNB's physical-layer-transmission capability (like the SeNB's modulation and coding scheme (MCS), carrier bandwidth, etc.) information via the Xn interface.

[0101] The MeNB can monitor the delay and delay jitter between the MeNB and the SeNB. The MeNB can determine a redundancy rate based on, at least, (1) an SeNB transmission capability, (2) the delay jitter over the Xn interface, and (3) a TDM pattern for switching. The MeNB can mirror a certain amount of user data to the SeNB considering and/or based upon the redundancy rate.

[0102] In the event of switching from the MeNB to the SeNB by the UE, the MeNB can inform the SeNB about the last data unit index via the Xn interface (another alternative is that the UE can inform the SeNB of the last data unit index via the Uu interface). The MeNB can transmit an indication of the time to switch.

[0103] In the event of switching from the SeNB to the MeNB by the UE, the MeNB can be informed of the last data unit index from the SeNB via the Xn interface (another alternative is that the UE informs the MeNB of the last data unit index via the Uu interface). The MeNB can remove the user data which has been successfully transmitted by the SeNB. The MeNB can start transmitting to the UE from the next data unit.

[0104] Next, from the perspective of the SeNB, during the preparation of switching between the MeNB and the SeNB, the SeNB can transmit the SeNB's physical layer transmission capability (like MCS, carrier bandwidth) information to the MeNB via the Xn interface. The SeNB can monitor the